Multiple drivers of invasive lionfish culling efficiency in marine protected areas

Múltiples impulsores de la eficiencia de la eliminación de peces león invasores en áreas marinas protegidas

Multiples facteurs l'efficacité de l'abattage du poisson-lion envahissant dans les aires marines protégées

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EXTENDED ABSTRACT

Rates of biological invasion and range expansion are increasing with climate change and habitat loss, making invasive species a threat to global biodiversity and a major conservation concern (Mooney & Cleland 2001). Because of the widespread impacts of many invasive species, particularly in aquatic ecosystems, intervention that involves removal or mitigation activities are a priority within many countries' conservation and natural resource management plans (Gallardo et al. 2015; David et al. 2017). Designing effective local management for invasive species poses a major challenge for conservation, yet factors affecting intervention success and efficiency are rarely evaluated and incorporated into practice. Here we focus on the invasive Indo-Pacific red lionfish (*Pterois spp.*) in the Atlantic Ocean, Gulf of Mexico, and Caribbean Sea to examine the efficacy and efficiency of population control activities across multiple jurisdictions in the invaded region. Our goal is to quantify the effort and success of invasive lionfish culling efforts in relation to a suite of environmental and biological characteristics of the invaded system and characteristics of the personnel engaged in culling activities. Specifically, we ask: (1) What factors affect the efficiency (time) and efficacy (likelihood of removing individuals, and proportion of individuals removed per event) of invasive lionfish culling events? and (2) How do capture efficiency and efficacy change over time during culling programs? The goal of our analysis is to illustrate how key variables affecting invasive species control activities can be incorporated into management planning to increase the efficiency and efficacy of ongoing suppression activities at local priority locations impacted by broadly distributed invaders.

We tracked lionfish removal efforts on 33 individual invaded coral reefs in four distinct marine protected area (MPA) management zones within three regions of the Western Atlantic, Gulf of Mexico, and Caribbean from 2013-2019 (Figure 1). The Flower Garden Banks National Marine Sanctuary in the Northwestern Gulf of Mexico (FGBNMS; N = 6 reefs), Biscayne National Park (BNP; N = 7 reefs) and Florida Keys National Marine Sanctuary (FKNMS; N= 12 reefs) in South Florida, and Buck Island Reef National Monument in the US Virgin Islands (BIRNM; N = 8 reefs). Studying removal at this scale allowed us to examine how regional variation in physical abiotic characteristics, biotic composition, invasion dynamics, and the characteristics of personnel involved in removal influence the efficacy and efficiency of invader suppression. During surveys, one diver from each pair attempted to remove all lionfish sighted using a spear, while the second diver recorded data on lionfish location and position on the reef, size, behavior, and the removal effort of their dive partner, including number of attempts at capture, the time spent in removal efforts per fish, and whether the fish was caught.

To evaluate our hypotheses about the effects of variables describing habitat, environment, invasion characteristics and remover characteristics on the efficacy and efficiency of invasive lionfish removal we constructed generalized linear mixed effects models (GLMMs). Specifically, we modeled three response variables: the probability of each lionfish being captured (0/1 binary), total proportion of lionfish removed (0-1 continuous) , and time (seconds) spent attempting to capture each lionfish (0-infinity, continuous) during a site visit. We used a binomial (link = logit) distribution for likelihood of removal, an exponential (family= gamma, link = log, dispersion = 1) distribution for time, and a beta distribution (link = logit) for the proportion removed.

Of the 10 factors we examined, site-specific lionfish densities and body sizes, reef size, remover experience, and the time of day during which culling took place had the largest effects on removal efficiency across all study regions. The success of culling activities varied little on reef sites varying greatly in biotic composition and structural complexity (range of gorgonian cover (0-50%) and complexity values (0.2-4m relief, 0-95% coral cover). Culling efficiency (proportion removed and likelihood of catching each fish) generally decreased as the size of the site increased (in this study, ranging from 0.02-0.78 hectares), while time spent attempting to cull each fish declined as reef area increased.

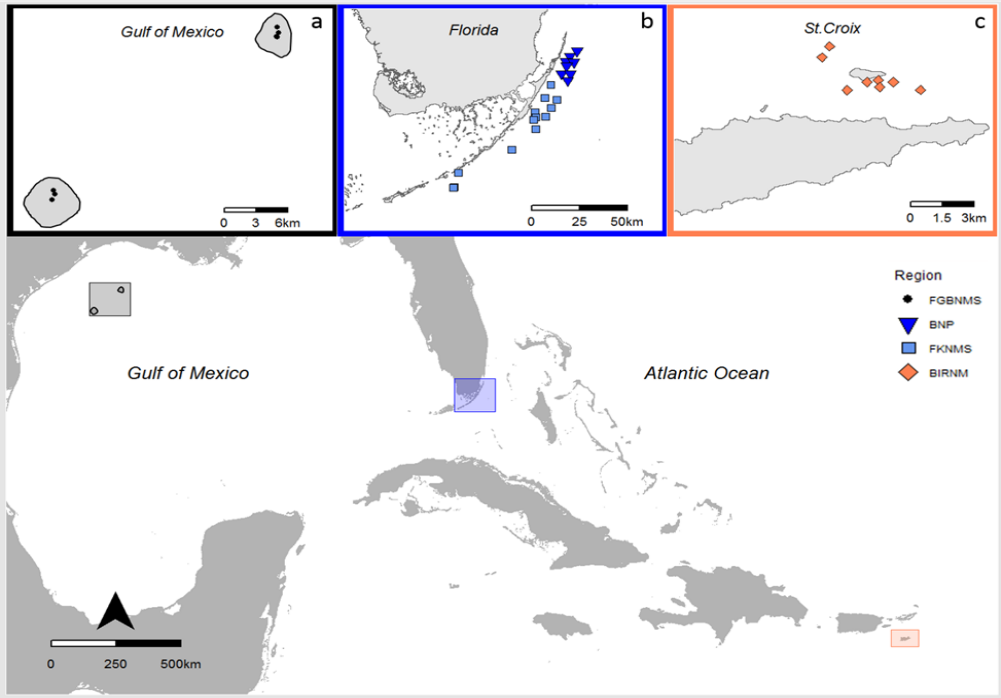

Figure 1. Locations of coral reefs where lionfish culling took place for this study in the four MPA management zones within three regions: a) Flower Garden Banks National Marine Sanctuary, in the Northwest Gulf of Mexico, USA, b) Florida Keys National Marine Sanctuary and Biscayne National Park, in South Florida, USA, and c) Buck

Highly experienced individuals culling during crepuscular periods (<2hrs from sunrise/sunset) are three times more efficient (in terms of minutes) than novice divers during midday, suggesting 1) retention of experienced individuals is key for efficient programs, and 2) planning culls with personnel and time of day in mind increases the number of sites covered with the same effort. Lionfish behavior and habitat characteristics had little effect on removal efficiency and efficacy, but divers had higher capture success at reefs with higher lionfish densities. We suggest reefs with persistently <20 fish ha-1 as low priority, given that impacts to native fauna are unlikely and culling effectiveness declines to <50% below this level. Incorporating efficiency factors in spatial management planning along with density estimates derived from remotely sensed data can ensure limited resources for control are extended across a greater range of invaded habitats.

KEYWORDS: invasive species, population control, functional eradication, removal efficacy, citizen science

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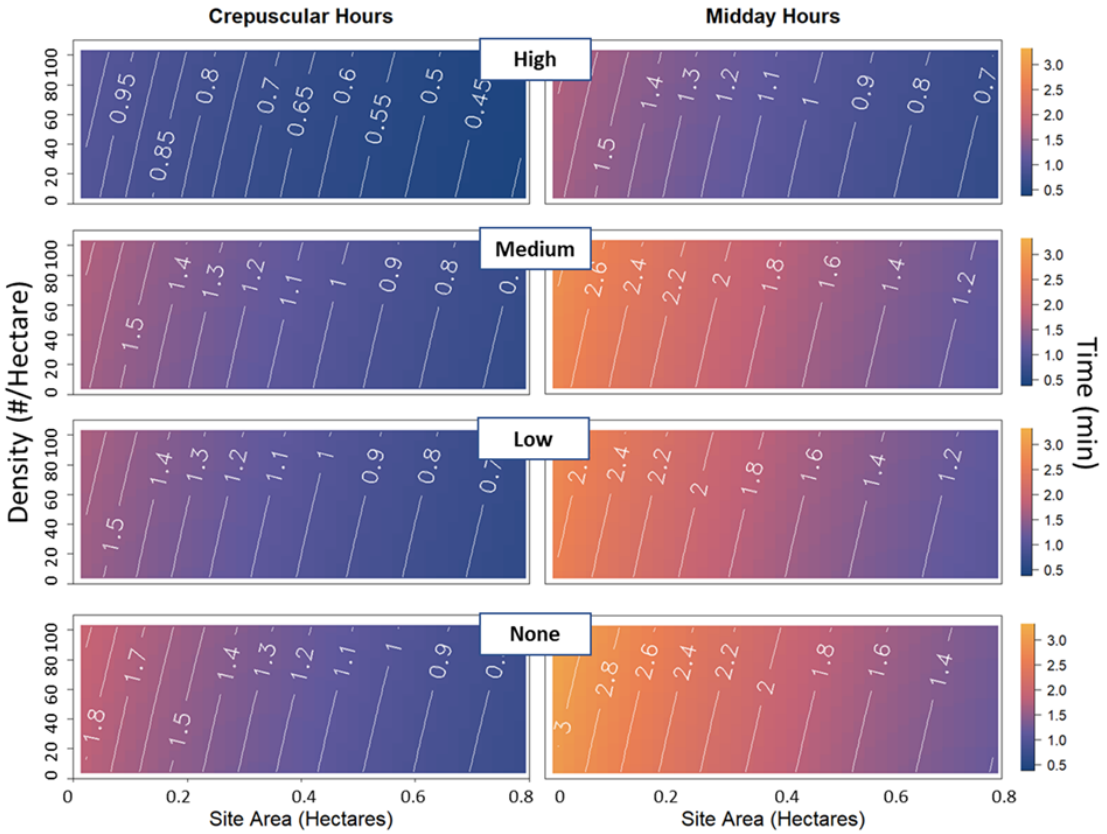

Figure 2. Heat plot showing the predicted amount of time to remove an individual lionfish during midday and crepuscular hours for all experience levels (High, Medium, Low, None) across all site area and lionfish density combinations. All other variables from the model are held constant at their mean.